



Dual-task costs in aging are predicted by formal education

Antonino Vallesi^{1,2} 

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Abstract The capacity to manage different concurrent tasks at the same time decays in older adults. There is however a considerable amount of inter-individual variability in this capacity even in healthy aging. The purpose of this empirical study is to investigate which factors help explaining this variability. A dual-task paradigm was administered to 64 older adults and 31 younger controls. In this paradigm, a primary simple response time task had to be carried out either by itself (single-task condition) or while concurrently performing a secondary subtraction task (dual-task condition). Dual-task costs were operationalized by comparing dual-task and single-task conditions. Older adults showed higher dual-task interference than younger controls. Within the older group, the influence of age, general cognitive abilities, performance on the secondary task, and years of formal education was assessed with a multiple regression analysis. The results showed that years of formal education in older adults were the best predictor that significantly explained a portion of the variance in dual-task performance. These findings extend previous literature by showing that formal education provides an important dose of cognitive reserve, which is useful to successfully implement cognitive dual-task management despite aging.

Keywords Dual-task interference · Cognitive aging · Education level · Cognitive reserve · Executive functions · Multiple regression

Introduction

The ability to manage multiple ongoing tasks in parallel is a constant requirement in everyday life. Dual-task research with older adults has shown that aging is accompanied by increased difficulty in performing different concurrent tasks across multiple domains (e.g., [1]). In particular, it has been shown that, in the aging population, dual-task situations not only interfere with controlled processes such as memorizing [2], but also with apparently automatized everyday activities such as speaking [3], driving [4, 5, 6], and walking [7, 8, 9, 2, 10, 11], although some differences have been observed depending on the automaticity and complexity of the tasks used (see [12], for a meta-analysis).

It has been suggested that higher order executive functions are implicated in divided-attention abilities required during dual-task management, such as in planning, decision making, and coordination (e.g., [13]). Thus, given the age-related increased inter-individual variability in executive functioning (e.g., [1]), it is not surprising that this variability is also specifically present in dual-task abilities among older adults [7, 14], above and beyond general slowing factors (e.g., [15]).

This variability is however poorly explained since the factors that contribute to dual-task-related decrements in performance that occur in aging are not completely understood. Converging evidence points towards an association between gait quality during dual-task situations and executive and affective functioning in aging (e.g., [16, 17]).

An under-investigated issue is whether a high level of cognitive reserve [18] may be associated with better management of dual-task situations. Cognitive reserve refers to the ability to tolerate the age-related and disease-related brain damage without developing cognitive deficits

✉ Antonino Vallesi
antoniovallesi@yahoo.it

¹ Department of Neuroscience, University of Padova,
Via Giustiniani, 5, 35128 Padua, Italy

² Centro di Neuroscienze Cognitive, Università degli Studi di
Padova, Padua, Italy

(e.g., [19, 20]) and/or clinical manifestations of disease [21, 22]. Several studies indeed demonstrate that, in the aging population, life experiences such as education, type of job, and leisure activities are associated with increased resilience to deficits including dementia and memory decline and allow some individuals to cope better than others with brain damage [22]. Unfortunately, cognitive reserve is a hypothetical construct, which is not possible to measure directly. Different proxy measures, latent variables, and composite questionnaires have been employed to attempt to operationalize reserve [23].

Childhood cognition is probably the best predictor of cognitive reserve, although it is difficult to obtain an estimate of it a posteriori [24]. Among the other factors taken into account by the literature, formal education has been considered as a better proxy of cognitive reserve than job occupation, and the two factors are independent from each other [25, 24]; cf., [26]. However, a possible reason for the observed weak relationship between occupation and cognitive reserve is that it has been considered as a crude and general measure (e.g., social class) and as such one might miss how more specific occupational skills may benefit cognitive processes [24].

A recent study [27] showed that formal education plays a more important role in explaining age-related differences in dual-task performance on cognitive tasks than on motor ones. This interesting seminal study manipulated dual-task interference by mixing different gait and cognitive tasks at the same time. It would also be useful to understand whether purely cognitive dual-task interference, with no gait motor tasks, would replicate the role of cognitive reserve and/or education in explaining age-related variance in this executive function measure. Moreover, this study involved a limited number of older adults ($N = 15$). Therefore, further investigation on this issue is warranted.

The present study aimed at further investigating the factors that contribute to cognitive dual-task performance variability in healthy older adults. We explored the role of age, general cognitive abilities (MoCA scores), but also cognitive reserve, operationalized with the scores obtained in a standardized questionnaire and/or with years of formal education, in predicting performance in a computerized dual-task paradigm.

Methods

Participants

Sixty-four older adults (mean age 68.9 years, range 58–85, 50 % females) voluntarily took part in the experiment. All participants gave informed consent prior to their recruitment. All had normal or corrected-to-normal visual acuity

and no history of neurologic/psychiatric disorders. All older participants but 3 were right handed, as assessed with the Edinburgh Handedness Inventory. All participants were administered with the Montreal Cognitive Assessment (MoCA). For participants older than 80 years, the closest age group was used as the reference group (75–80). None of the participants fell below the dementia cut-off of 2.5 standard deviations corrected for age and education level [28].

A control group of younger adults was also recruited to assess whether older adults had on average disproportional dual-task costs with our paradigm, and thus check whether our data could replicate the pattern already observed in the existing literature. This group was composed by 31 university students (mean age 23 years, range 20–28, 64 % females) with normal or corrected-to-normal visual acuity and no history of neurologic/psychiatric disorders. All younger participants but two were right handed, as assessed with the Edinburgh Handedness Inventory [29].

The study was approved by the Bioethical Committee of the Azienda Ospedaliera di Padova and was conducted according to the guidelines of the Declaration of Helsinki.

Apparatus and stimuli for the dual-task

Participants viewed the screen at a distance of approximately 60 cm. The foreperiod (FP) lengths used were 3 and 5 s. FPs were long enough to provide participants with enough time to engage in the task before being required to respond, even in the shorter FP. At the beginning of the single-task, a 'XX' was displayed in the center of the screen. This double X was substituted by a two-digit number (starting minuend) in the subtraction tasks. Together with this initial cue, an auditory warning stimulus (a 1500 Hz pure tone) was presented for 50 ms through speakers. The target stimulus, which was presented at the end of the FP, was a downward pointing white arrow (with maximum length and width of 2 cm).

Tests and procedure

The task was similar to that published by Vallesi and colleagues [30]. An initial familiarization phase with 30 computerized trials and a simple response time task preceded the dual-task test (data not reported here). Two blocks with 120 test trials were presented during the dual-task session. In every dual-task block, half of the trials belonged to a single-task condition, and the other half to a dual-task one. Trials with the different tasks (single vs. dual) and FPs (3 vs. 5 s) were administered pseudo-randomly but equiprobably, in order to obtain approximately the same number of trials per condition. As the secondary task, participants had to progressively subtract the

subtrahends 1, 2, 3, 4, and 5 from a starting minuend and the subsequent results. Verbal responses were recorded during the subtractions to allow offline analysis of the accuracy of this secondary task. Two-digit numbers randomly drawn from 27 to 90 were used as the starting minuend. Participants were instructed to verbally subtract as many numbers as possible before the target onset. They were also aware that the subtraction task was the secondary task which should be performed without penalizing the primary task, that is, pressing the spacebar of a computer keyboard as quickly as possible at the end of the FP, which was marked with the appearance of a target arrow. Therefore, they were clearly instructed that, at the target onset, they had to immediately interrupt the subtraction task at whatever point it was and quickly perform the primary RT task. To ensure that they understood the instructions and had a minimal familiarization with the tasks, apart from the initial simple RT task with 30 trials, 4 training trials (including 50 % of single-tasks and 50 % of dual-tasks) preceded the real test sessions.

At the end of the computerized dual-task paradigm, older adults were administered with a measure of cognitive reserve, namely the Cognitive Reserve Index Questionnaire (CRIq, [31]; also see [32]). This tool quantifies cognitive reserve for the Italian population. The cognitive reserve index is calculated by weighting the contribution of factors, such as years of formal education, occupation, and activities (sport, leisure, and cultural) that had been carried out during the entire adult lifetime. Moreover, older adults were also administered the Montreal Cognitive Assessment (MoCA; [33]), as a measure of general cognitive abilities. Since clinically relevant dementia was an exclusion criterion, the MoCA was always administered at the beginning of the testing session.

Data analysis

Trials with RTs outside the 100–2000 ms range with responses occurring before the target onset and null responses were discarded from further analyses. The first trial of each block was eliminated because it was not preceded by any previous FP. For the mean RT analysis, an initial $2 \times 2 \times 2$ mixed ANOVA was employed with task (single-task vs. dual-task), FP (3 vs. 5 s) as the within-subject factors and group (younger vs. older) as the between-subject factor. This preliminary analysis did not show any interaction between foreperiod and age group (cf., [34], for different behavioral results obtained inside the MRI scanner). Therefore, the factor foreperiod was collapsed in the analyses reported here.

For the secondary subtraction task, accuracy was measured as the percentage of correct subtractions performed before target onset. We checked group differences on the

performance of this subtraction secondary task with an independent samples *t* test.

Results

Accuracy for the primary task

Misses were on average 1.5 % of trials (older = 1.82 %, younger = 0.9 %). Responses outside the 150–2000 ms range were almost absent. Responses during the FP (anticipations) were on average 1.36 % (older = 1.82 %, younger = 0.9 %).

Response times (RTs) for the primary task

RTs are reported in Table 1. The group main effect showed that older adults were slower than younger controls [$F(1,93) = 24.4$, $p < 0.00001$, partial eta squared = 0.207]. The task main effect showed that RTs were longer for the dual-task than for the single-task [$F(1,93) = 140.49$, $p < 0.00001$, partial eta squared = 0.602]. There was also an interaction between task and age group [$F(1,93) = 4.07$, $p < 0.046$, partial eta squared = 0.042]. This interaction showed that older adults had more pronounced dual-task costs than younger adults (242 vs. 171 ms). However, Tukey's HSD tests showed that both groups had reliable dual-task costs (for both, $p < 0.001$).

Secondary task efficiency

The percentage of correctly performed subtractions for each age group is reported in Table 1. An independent samples *t* test showed that older adults' performance on the secondary task was on average worse than that of younger adults [$t(93) = -3.17$, $p = 0.002$; correct subtractions within the foreperiod deadline = 38 vs. 45 %, respectively].

Multiple regression analysis

A multiple regression was conducted in the older adult sample, to assess which factor was the best predictor of dual-task costs during aging. It was decided to include age in the model since it was shown to correlate with dual-task interference (e.g., [1]). In order to also control for general cognitive abilities, MoCA scores were included in the model. Since both younger and older adults usually place greater priority on the secondary task in many dual-task contexts (e.g., [35]), a measure of secondary task efficiency (operationalized as the mean percentage of subtractions successfully completed before the target onset) was also taken into consideration in the regression analysis to control for its contribution. Years of education were chosen

Table 1 Mean RTs (in ms) for the primary task and mean percentage of correct subtractions in the secondary task (and standard deviations) for each age group and task type

	Younger adults		Older adults	
	Single-task	Dual-task	Single-task	Dual-task
Primary task RTs (ms)	341 (43)	512 (87)	471 (167)	713 (235)
Secondary task (subtraction) % correct	–	45 (7.9)	–	38 (10.7)
MoCA			25 (3)	
CRI-education			118 (17)	
CRI-working activity			122 (25)	
CRI-leisure time			110 (18)	
CRI-global score			122 (19)	

For the older adults only, scores at the Montreal Cognitive Assessment (MoCA) and Cognitive Reserve Index Questionnaire (CRIq, subscales and global score) are also reported

instead of the Cognitive Reserve Index because preliminary regression analyses showed that the two regressors were highly collinear (correlation $r = 0.85$) and produced a bad model ($R^2 = 0.099$, $F = 1.28$, $p = 0.28$). Moreover, the model including the years of formal education only performed slightly better ($R^2 = 0.15$; $F = 2.66$) than that including the Cognitive reserve index ($R^2 = 0.14$; $F = 2.46$), although both regressors significantly predicted dual-task costs (for both, $p < 0.05$). After deciding which relevant variables to include, a multiple regression analysis was conducted to assess if age, years of education, MoCA scores, and secondary task (subtraction) efficiency predicted the dual-task costs. The enter multiple regression method was used. First, the steps to verify whether the underlying assumptions were met or not will be reported. An analysis of standard residuals was carried out on the data to identify any outliers, which indicated that one participant's standard residual value was outside the range of ± 2 (i.e., 2.679 and 3.527). Tests of collinearity indicated that multicollinearity was not a concern (age, tolerance = 0.69, VIF = 1.44; education, tolerance = 0.74, VIF = 1.33, MoCA, tolerance = 0.55, VIF = 1.8; subtraction efficiency, tolerance = 0.68, VIF = 1.47). The data met the assumption of independent errors (Durbin–Watson value = 2.27). The normal probability plot of standardized residuals showed points that were almost completely on the line, apart from two possible outliers (see below). The scatterplot of standardized residuals suggested that the data met the assumptions of homogeneity of variance and linearity apart from two possible outliers (see below). The data also met the assumption of non-zero variances. When the multiple regression analysis was run on the whole dataset, it was found that all the selected regressors explained a significant amount of the variance in the dual-task costs [$F(4,59) = 2.66$, $p = 0.0416$, $R^2 = 0.15$, R^2 adjusted = 0.09]. The only regressor that significantly predicted dual-task costs was years of education [$\beta = -0.38$,

$t(59) = -2.77$, $p = 0.007$; semi-partial correlation = -0.33 , $R^2 = 0.25$]. Apart from a tendency of age [$\beta = 0.25$, $t(59) = 1.75$, $p = 0.084$], no other regressor significantly predicted dual-task costs (for all, $p > 0.35$), although the amount of explained variance was in general not negligible (for all, $R^2 > 0.30$). Since preliminary checks showed the presence of two possible outliers, the multiple regression analysis was re-run after removing them from the dataset. The results showed that, while the whole model performed slightly worse [$F(4,57) = 2.16$, $p = 0.08$, $R^2 = 0.13$, R^2 adjusted = 0.07] than with the entire dataset, the critical regressor, that is, years of education, was still significantly predicting dual-tasks costs [$\beta = -0.37$, $t(57) = -2.58$, $p = 0.012$; semi-partial correlation = -0.32 , $R^2 = 0.25$].

Discussion

The present study investigated which factors predict cognitive dual-task interference in healthy aging. The results first replicated the well-known effect that older adults suffer from dual-task interference more than younger controls. Within the older group, the explanatory roles of chronological age, general cognitive abilities (MoCA scores), secondary task efficiency, education, and/or cognitive reserve were assessed with a multiple regression analysis. The results highlighted the role of education, above and beyond all the other considered factors, as the best predictor of dual-task cost variability in healthy aging.

This study replicated previous findings [27] by using different cognitive tasks and a bigger sample size. The present study additionally extended these previous findings obtained in the context of a mixture of gait and cognitive dual-task performance, by showing that, within the group of older adults, education reliably predicts purely cognitive dual-task performance. Moreover, semi-partial correlation results demonstrated that formal education still

significantly predicted dual-task costs in older adults after controlling for chronological age, general cognitive abilities (MoCA scores), and secondary task efficiency.

The present findings reinforce the idea that education contributes to cognitive reserve even within the healthy aging population, and not only as a compensatory factor in the clinical manifestation of cognitive decay in dementia [21, 25]. It should be acknowledged that the formal education level may be viewed as an incomplete measure of cognitive reserve, since it is typically acquired relatively early in life and it does not usually change afterwards. However, education may increase the predisposition for greater physical and mental stimulation during the entire lifetime which, in turn, may generally contribute to greater cognitive reserve [25] and, more specifically, to higher flexibility in dual-task contexts, as shown here and elsewhere [27].

Indeed, preliminary analyses also showed that the years of formal education had a high redundancy with respect to a more complex measure of cognitive reserve, that is, the global score on the CRIq [31]. One partial reason could be that the years of formal education are included in the CRIq and weighted together with other factors in order to obtain the global cognitive reserve scores. However, the effect of education is somewhat diluted together with that of the other factors. Therefore, it seems that, for the cognitive dual-task performance assessed here, the relevant cognitive reserve that explains its variability within the healthy older population is already provided by education per se. Future studies should try to understand whether different measures of cognitive reserve not considered here, which should be uncorrelated with years of education, could also predict other portions of age-related executive function variance at the same level or better than education per se.

It is worth mentioning that, although significant, the portion of the variance explained by education level was a moderate 25 %. Therefore, a large portion of the data needs to be explained with other potential factors not considered here. For instance, the presence of many data points lying within the bottom left quadrant of the scatterplot in Fig. 1 demonstrates that several older individuals, despite few years of education, still performed the dual-task reasonably well, at least as well as their peers who instead had a much higher level of formal education (plotted in the upper left quadrant). Other factors, including those considered in the present regression analysis, may explain the rest of the variance, although in our analysis they did so without reaching statistical significance. Further investigation is therefore advisable to unveil other and more reliable possible mechanisms by which dual-task performance is well preserved in some highly functioning older individuals.

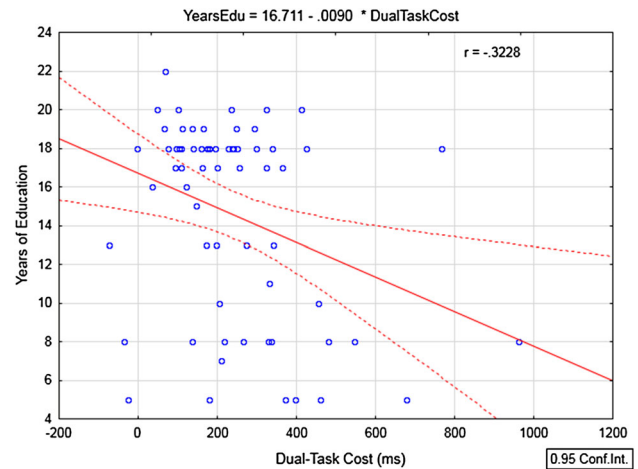


Fig. 1 Scatterplot of the bivariate correlation between years of formal education (y) and dual-task costs in ms (x)

The role of factors, such as the specific job, sport and leisure activities, as well as genetic characteristics, are all worth investigating in future research.

It is also interesting to note that the ability to perform the secondary mathematical task did not play any role in explaining dual-task costs on the primary response time task, suggesting that education in general, and not the skills specifically required in the secondary task, is the critical factor here (also see [27]).

A possible limit of the present study is the mismatch between the education level in the younger controls (all university students) and in some of the older adults. This might have inflated performance differences between the two age groups and future studies should certainly try to match education level more between the two groups (although there will be unavoidable cohort effects). However, the critical regression analysis reported here was focused on the older adults only, and as such it did not suffer from this limitation.

In conclusion, the results of this study show that formal education is an important factor influencing an executive function such as the management of cognitive dual-task performance in healthy aging. Future studies should determine which is the exact cascade of dynamic mechanisms and events through which such an (usually) early and static life feature may mediate executive functioning during aging.

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Conflict of interest None.

Ethical approval The study protocol was in accordance with the Helsinki Declaration on human rights and was approved by the Bioethics Committee, Azienda Ospedaliera di Padova.

Informed consent All participants signed an informed consent form prior to their inclusion in the study.

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